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HYDROGEOLOGIC CONSIDERATIONS IN THE SITING AND DESIGN OF LANDFILLS

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HYDROGEOLOGIC CONSIDERATIONS IN THE SITING AND DESIGN OF LANDFILLS

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INTRODUCTION

If refuse buried in a landfill comes in contact with water, an obnoxious, mineralized liquid called leachate is produced. The leachate commonly moves as underground water. In most landfills in humid areas reliance is placed on natural processes to reduce the dissolved solids content of the leachate to tolerable levels before it can reach a point of water use. If we can judge from the limited number of recorded cases of ground- and surface-water pollution from landfills, this procedure has been relatively successful. However, most landfills have been located in out-of-the-way places, are not close to water wells, and have not been monitored.

The hydrogeology of a landfill site controls the movement of water through the refuse and, therefore, affects the rate at which the refuse decomposes and leaches. This in turn affects the production and concentration of the leachate, the compaction of the landfill, and the time required for the landfill to become chemically and biologically stabilized, with consequent cessation in production of dissolved solids. The hydrogeology of the site also controls the migration and attenuation of the dissolved solids of the leachate as they are carried by ground water.

Some landfills will have no appreciable effect on the surrounding ground and surface waters. Others, however, may seriously degrade these waters, and the effect of this degradation may be difficult to overcome. Therefore, before a landfill can be properly designed the hydrogeologic environment of the landfill site must be known.

Some of the effects of hydrogeologic factors on landfills and the relation of these factors to landfill design under the geologic and climatic conditions prevailing in northeastern Illinois are described here. Concepts rather

than specific designs or engineering criteria are suggested and some acquaintance with landfills and hydrogeology on the part of the reader is assumed. The conclusions reached are applicable in other areas only insofar as conditions are similar to those in northeastern Illinois. In particular, caution should be exercised in applying these conclusions in arid climates and in terranes of soluble limestone where the top of the zone of saturation is deep and flow is through solution openings in the rocks.

The application of procedures outlined here to specific disposal sites in Illinois must be approved by the Illinois Environmental Protection Agency, which is responsible for regulating landfills in the state.

HYDROGEOLOGIC CONDITIONS

Three hydrogeologic factors affect the design of landfills in Illinois: (1) the position of the landfill site within the ground-water flow system; (2) the position of the top of the zone of saturation, or water table, with respect to the refuse; and (3) the texture and composition of the surrounding earth materials, which affect their ability to transport and attenuate dissolved solids in the leachate. Dissolved solids include all organic and inorganic components dissolved in the ground water.

Position Within Ground-Water Flow System

A landfill situated near a ground-water recharge zone, where the ground-water gradient is downward, could introduce dissolved solids into the underlying aquifers. Recovery of these dissolved solids before they reach a useful source of water would likely be difficult.

Dissolved solids moving from landfills located near ground-water dischar zones (where ground-water movement is upward) may migrate laterally, but will remain close to the top of the zone of saturation. They are therefore unlikely to reach underlying aquifers. As ground-water discharge zones are in most cases associated with lakes, streams, or swamps, dissolved solids from a landfill in a ground-water discharge zone could reach surface water bodies. However, dissolved solids will be attenuated to some extent during their travel through the soil and in many cases will be considerably diluted when they reach the surface water. Because the dissolved solids leaving landfills near discharge zones remain relativel close to the ground surface, they can be more easily controlled by tiles or wells than would be the case if they moved deeper beneath the landfill.

Position of Top of Zone of Saturation

If refuse is buried below the top of the zone of saturation (water table), it will be in contact with ground water, and leachate will be produced. In arid climates where precipitation is too low to infiltrate the surface of a landfill, no leachate is produced if the refuse is buried above the top of the zone of saturation. In humid climates, such as that in northeastern Illinois, precipitation usually infiltrates the surface of a landfill and produces leachate, even if the site is above the top of the zone of saturation.

Apgar and Langmuir (1971, p. 78 and 93) in studies of landfills in Pennsylvania also concluded that in humid climates leachate should be anticipated in landfills, even though they may be above the top of the zone of saturation. They also pointed out that in permeable soils and rock such landfills may cause more serious ground-water pollution than deposition of the same wastes in an impervious zone below the water table. Under such circumstances, restricting deposition of refuse to sites above the water table is an inadvisable precaution.

As will be noted later, sites where the refuse does not intersect the top of the zone of saturation are rare in northeastern Illinois. Most of such sites are recharge areas in permeable materials where the potential for polluting the ground water and for lateral migration of landfill gases is highest.

In humid climates, a ground-water mound often forms in a landfill that intersects the top of the zone of saturation, particularly where the surrounding materials have low to moderate permeability. A mound develops (ground-water gradient increases) because more water is infiltrating through the surface of the landfill than can be moved out through the sides and base at the original ground-water gradient. Our work to date in northeastern Illinois indicates that ground-water mounds will be present under most landfills—the exceptions being those that have been constructed in relatively permeable gravels and sands. The presence of a ground-water mound shows that precipitation is infiltrating through the landfill surface, and, once such a mound forms, the ground-water gradient is away from the landfill. Under these conditions, even if the refuse has been placed in the zone of saturation, ground water can no longer contribute to the production of leachate, inasmuch as flow is outward from, rather than into, the landfill.

If infiltration is sufficiently low and the landfill is in materials with high permeability, no ground-water mound may form, and ground water may move through the refuse and produce a leachate. The amount of ground water that will move through the refuse will depend on the position of the landfill in the ground-water flow system. If there is a large horizontal component of ground-water flow, more water will flow through the landfill and more leachate, though possibly less mineralized leachate, will be produced. Conversely, if the horizontal component of flow is small, less leachate, but possibly more mineralized leachate, will be produced by the ground water. Here again, the major source of leachate is likely to result from infiltration through the surface of the landfill.

If, as is generally the case, the landfill surface is higher than its surroundings and a ground-water mound forms, springs or seeps may emerge around the margin of the landfill. The springs or seeps can be eliminated by reducing the size of the ground-water mound, which can be done by reducing infiltration or draining leachate from the landfill. They may also be eliminated by constructing the slope of the ground surface around the margin of the landfill so that it has a lower gradient than the slope of the top of the zone of saturation.

The position of the top of the zone of saturation with respect to the buried refuse also should be considered in the design of the landfill cover and the collection facilities. In a landfill located above the top of the zone of saturation it may be possible, particularly in arid and semi-arid climates, to construct a cover that would minimize infiltration and thus reduce the production of leachate.

Where a landfill is constructed above the top of the zone of saturation, it is not possible to collect leachate "hydrologically," that is, to manipulate the level of the top of the zone of saturation with tiles or wells within or at the base of the landfill in order to create a ground-water gradient into the site. Under these circumstances, collection of leachate could be accomplished only by wells or tiles in the zone of saturation below the landfill or above an impermeable membrane within the landfill.

Earth Materials

Earth materials with low permeability (on the order of 10^{-7} centimeters per second, or less) (fig. 1), such as the silty clay tills in northeastern Illinois, will retard the movement of leachate and will also significantly reduce the dissolved solids content of leachate within a relatively short distance. Natural containment of leachate is, therefore, possible in landfills constructed in earth materials of low permeability, and, in many cases, subsurface leakage from these landfills will be minimal. However, there are disadvantages to constructing landfills in such materials. For example, springs and seeps may develop around the margin of the landfill. In addition, earth materials with a high clay content are difficult to work, and, if used for a cover, may crack in dry weather, forming vents for the escape of landfill gases or providing funnels for rain or surface water to enter the fill.

Earth materials with high permeabilities (on the order of 10^{-1} cm/sec or more), such as gravels or sands and certain fractured rocks, are likely to allow the subsurface movement of significant amounts of leachate from the disposal site and are much less efficient in attenuating dissolved solids. However, there is less likelihood that springs and seeps will form around a landfill in materials of high permeability and, in addition, gravel and sand are easily worked.

Landfill Gases

As the organic constituents in landfills decompose, various gases are produced. The main problem-producing gases are methane, carbon dioxide, and gases with obnoxious odors. Methane is the most hazardous of landfill gases because it forms an explosive mixture with air (5 to 15 percent methane with air). Carbon dioxide increases the hardness and acidity of water; acidity, in turn,

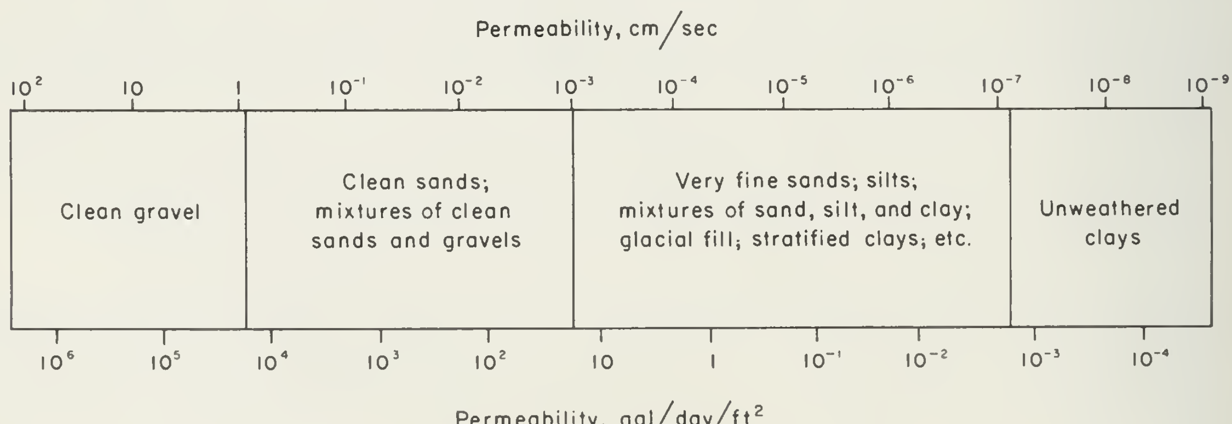

Fig. 1 - Range in permeability of different soil classes (modified from Todd, 1959, p. 53).

increases the solution and leaching of soluble constituents in the refuse and surrounding earth materials.

Landfill gases can migrate through permeable unsaturated materials for considerable distances. Studiės in California (Engineering Science, Inc., 1963-1966) indicated that problems from gas migration to adjacent property should be anticipated in environments where the refuse is emplaced in permeable materials above the top of the zone of saturation. This would include landfills in thick, unsaturated gravels or high above-ground landfills. These types of environment are seldom used for landfills in northeastern Illinois.

The installation of a thick, impermeable cover to reduce infiltration may impede the movement of gases up through the landfill surface and force them to move laterally.

Venting (Eliassen, O'Hara, and Monahan, 1957, p. 115) and burning (Engineering News-Record, 1948, p. 86; Dunn, 1960, p. 68) are the most common procedures for dealing with landfill gases to prevent odors and explosions. To date, however, there is little documentation of the effectiveness of the various venting methods under differing conditions. Design of gas-tight structures for sanitary landfills was discussed by Sowers (1968, p. 115) and First, Uiles, and Tevin (1966).

HYDROGEOLOGIC ENVIRONMENTS IN NORTHEASTERN ILLINOIS

The surficial deposits of northeastern Illinois are primarily of glacial origin and exhibit the variability typical of such deposits. In the eastern two-thirds of the area, the bedrock just below the glacial deposit is primarily fractured dolomite of Silurian age, whereas to the west the bedrock is mainly shale of Ordovician age. Ground-water supplies have been developed from sand and gravel aquifers within the glacial drift and from the underlying bedrock, particularly from the Silurian, and because these aquifers are a major source of water in the area, the deterioration of these waters must be prevented.

Silty clay till with low permeability is a common surficial deposit east of the Fox River, and many landfills that rely on natural confinement have been constructed in this material. However, sand and gravel stringers with higher permeability are often interbedded in the till. West of the Fox River much of the glacial till is somewhat sandier and more permeable.

Sand and gravel outwash is common along the stream valleys and as outwash plains in parts of Will, Kane, Lake, Du Page, and McHenry Counties. Sand and gravel is also present in the morainal uplands as kame deposits, particularly in McHenry, Kane, and Lake Counties.

Under natural conditions a ground-water discharge zone borders all of the permanent streams, lakes, and swamps in northeastern Illinois; however, there has been extensive ground-water development in this area, and it is possible that some former discharge zones are now recharge zones, supplying water to nearby wells.

In most of northeastern Illinois the top of the zone of saturation is within 10 feet of the ground surface. It may be deeper in upland recharge areas composed of permeable materials or along valley bluffs where underdrainage occurs.

ENGINEERING CONSIDERATIONS

In an environment that does not provide natural protection a number of engineering techniques can be used to control the production of leachate and the migration of leachate from landfills. These techniques have been little used to date in the construction of landfills and have not been adequately field tested. Therefore, they will probably be modified by future experience.

Liners

Liners can be designed either to reduce or to eliminate the movement of leachate out of a landfill site, or to reduce or eliminate the movement of ground water into a landfill site. If designed to confine leachate, a liner must be very carefully constructed. Rupturing this type of liner could in some cases be equivalent to removing the plug from a bathtub and could cause uncontrolled, and probably undetected, movement of leachate into the subsurface.

In a landfill that penetrates the water table and in which the leachate is collected hydrologically by internal pumps or drains, a ruptured liner would allow additional water to enter the landfill. However, such a rupture would not allow movement of leachate out of the landfill into the ground-water reservoir as long as the collection system functioned. It therefore would have a less harmful effect than would be the case in landfills in which collection of leachate was not provided.

If water infiltrates the surface of a landfill constructed with a liner intended to eliminate the inward or outward movement of water, the landfill will eventually fill and the water will leak out of the landfill over the top of the liner. If there is no seepage over the top of the liner, the liner is probably leaking, letting leachate escape into the subsurface. It may be necessary to include collection and treatment facilities in landfills of this type.

Several types of liners can be constructed, and the selection of a particular liner will depend on the purpose for which it is intended and on the availability and cost of the liner materials. Earth liners are generally made of earth materials containing a relatively high percentage of clay and may have a permeability on the order of 10^{-6} centimeters per second or lower. An earth liner can be compacted to approach maximum density and can be treated with additives such as bentonite, lime, asphalt, or cement to reduce its permeability by several orders of magnitude. Most earth liners will allow a certain amount of leakage; however, this amount can be calculated and would generally be minor.

Liners can also be constructed of plastic or other materials that are, for all practical purposes, impermeable. However, plastics can be punctured during installation and during the operation of the landfill. A cover of soil is usually necessary to prevent punctures.

Several publications deal with various types of liners for lagoons and canals, but few deal with liners in refuse disposal sites. Some publications that may be useful are: U. S. Dept. Interior (1963), Dirmeyer (1969), Sherard et al. (1963), Solid Wastes Management (1971), Lauritzen (1961), and Johnson, Jacobson, and Schwab (1962).

Covers

In northeastern Illinois, studies by Hughes, Landon, and Farvolden (1971) showed that 40 to 50 percent of the annual precipitation infiltrates the surface of an ungraded, weed-covered landfill to produce leachate. Julius Dawes (personal communication, 1972) of the Illinois State Water Survey, Urbana, Illinois, estimated that of the approximately 33 inches of precipitation falling annually in northeastern Illinois, it is possible that all but about 2 inches could be excluded from the landfill fairly readily by having proper slopes, cover material, and vegetation. He suggested that infiltration might be reduced still further, though probably not completely eliminated, by installing a system of surface drains and terraces.

Runoff from and infiltration into a landfill are controlled by three interdependent factors, other than surface area: the composition and thickness of the cover material, the grade or slope of the cover, and the vegetation. The same factors affect the erosion of the cover. The eventual use of the landfill site and the availability of cover materials will probably dictate the grade, the soil, and the vegetation used, and, consequently, the amount of infiltration. Therefore, before the landfill can be designed, a decision must be made as to the eventual use of the site—whether it will be converted to a park or a golf course requiring irrigation, to a parking lot with sewers, or to some other use. The amount of infiltration can be estimated once the final use is determined.

If refuse is exposed by erosion of the cover, it must be reburied. Therefore, unless permanent maintenance is planned, proper design of the cover is particularly important.

Few criteria are available on which to base the selection of appropriate slope, cover material, and vegetation. It may be possible to estimate the proper grade to be used from near-by natural slopes on similar materials; however, considering all the variables involved, the grade should be estimated by some one experienced in this field.

As noted earlier, a properly designed cover will, by reducing infiltration through the landfill surface, tend to reduce the height of the groundwater mound within the landfill, thus reducing or eliminating seepage around its margin. The cover will also affect the decomposition, leaching, and settlement of the landfill. Final stabilization of the fill might be hastened by actually encouraging infiltration and possibly by adding nutrients such as domestic sewage to the infiltrating water.

Publications by Richey, Jacobson, and Hall (1961) and Luthin (1957) dealing with agricultural drainage may prove useful to designers of landfill covers.

Drainage and Collection Systems

Drainage and collection systems can be installed in landfills to control surface springs or to collect leachate. A system designed to control surface springs might be as simple as a single drainage line installed below ground surface around the margin of the landfill.

Draining a Landfill Above Zone of Saturation

A drainage system to collect all of the landfill leachate would generally be more complicated to construct. If the landfill is above the top of the zone of saturation, a closely spaced system at the base of the landfill, possibly installed in a permeable blanket of gravel and above a liner, may be necessary. If this system is to collect all of the leachate, the liner must be impermeable. A drainage system in a landfill in materials of low permeability, or in high-permeability materials with a low-permeability liner, would in many cases reduce leachate movement out of the landfill to minimal levels.

The efficiency of the particular system will depend on the spacing of the drains and the permeability of the surrounding materials. Once leachate has moved below the drains in landfills that are above the top of the zone of saturation, it cannot be induced to move upward into the drains again.

Draining a Landfill Below Zone of Saturation

If the landfill extends below the top of the zone of saturation, a system of drains or pumping wells can be installed within or just below the landfill to create a hydraulic gradient into it, which would essentially eliminate the movement of leachate out of the site. The drains will be most effective and probably simplest to construct if they are placed at the bottom of the landfill.

Construction of drain systems in landfills that extend below the top of the zone of saturation is simpler than that for landfills above the top of the zone of saturation. In the first type, proper operation depends on placing the level of the outlet so that a ground-water gradient is maintained into the site. In the latter type, operation depends on grading the drains downward to the outlet.

Leachate can be collected in a sump and drawn off by a pump or gravity system to a treatment facility. A gravity drainage system has the advantage of not requiring the supervision and maintenance necessary for a pumped system. If the completed landfill is to be used as an industrial park or for some other purpose involving facilities that require permanent maintenance, the pumping system for the landfill could easily be included in plans for maintenance.

In a system below the top of the zone of saturation, the level of the outlet should be kept low enough for continuous flow, and a ground-water gradient into the site must be maintained. The volume, and in a general way the concentration of the effluent, could be regulated by controlling the level of the outlet; the lower the outlet, the more leachate will flow.

Richey, Jacobson, and Hall (1961) and Luthin (1957, 1966) discussed the design of tile drainage systems.

Treatment

No adequate study of the treatment of leachate from landfills has been made as yet. However, preliminary results from an investigation in Wisconsin (Ham et al., 1971) indicate that anaerobic treatment of raw leachate with detention times of 10 to 12 days or more is promising, as is treatment of leachate mixed with domestic sewage by the activated sludge process. Up to 5 percent leachate by volume may be mixed with domestic sewage without reducing the effectiveness of the sewage-treatment process.

At a landfill currently under construction near Toronto, Canada, leachate is collected in underdrains and conducted to a pond. When the pond is full, the leachate is pumped back onto the top of the landfill. This procedure allows the operator to postpone the design and construction of the treatment facility until an estimate of the quantity of fluid involved can be made.

The design of the cover and the liner will affect the design of the treatment facilities. A landfill designed to promote infiltration through the cover will produce a larger quantity of leachate than one designed to restrict infiltration, but the leachate would probably be less concentrated and produced more quickly.

Monitoring

Facilities for monitoring water quality should be included in the design of a landfill for several reasons. Such facilities would give early warning if the design of the landfill were inadequate, they would provide a basis for evaluating claims of water pollution in the area, and they would provide information for the regulatory agency concerning the efficiency of various landfill designs.

Problems in Use of Completed Landfill

When a landfill has been completed, it presents some problems if construction is planned on the site. These include settling of the fill and the production of gases. Settling will be affected by the rate at which the refuse decomposes, which in turn is related to water movement through the landfill and the degree to which the refuse has been compacted during the filling.

Gases may create problems in landfills, particularly if the fill has been placed in permeable materials above the top of the zone of saturation. As noted previously, the ultimate use of the filled area should be considered when the landfill is being designed.

EXAMPLES OF LANDFILL DESIGNS

In the following section, conceptual designs for landfills in four different environments in humid climates are proposed. Similar techniques can be applied to other environments, but each landfill must be considered individually.

Environment 1—Low-Permeability Materials, Recharge Zone, Below Water Table

Figure 2 illustrates a landfill in materials of low permeability in a recharge area in which the refuse is placed below the top of the zone of saturation. Such an environment may be found in till plains and lake plains and in morainal uplands away from lakes and streams. It is an environment common in northeastern Illinois and is often used for landfills. If a previous excavation exists, it is likely to have been a clay pit, a strip mine, or a highway borrow pit.

Under natural conditions (fig. 2a), movement of leachate out of the landfill in the subsurface will be slow, and the capacity of the surrounding materials to attenuate the dissolved solids will be high. Therefore, the leakage through the base and sides may not produce a pollution hazard. If the landfill has steep sides and is higher than the surrounding area, marginal springs and seeps may form around its margins. Their significance will depend on the local situation and on the eventual use of the filled area.

The total amount of water moving out of the landfill can be estimated by using the Darcy equation,

$$Q = PIA,$$

where Q = the rate of flow
P = the permeability of the medium
I = the hydraulic gradient, the rate of change of hydraulic head along a flow path, dh/dl
A = cross-sectional area through which flow occurs

The amount of water moving out of the landfill as springs and seeps on the ground surface can be reduced or possibly eliminated (fig. 2b) by decreasing the slope at the margin of the landfill and/or by constructing a cover designed for maximum runoff. If this is not practical, drains at the edges of the landfill to conduct leachate to a treatment facility would also achieve this purpose.

If all the dissolved solids must be contained at the site, drains could be installed at or near the base of the pit (fig. 2c). This would create a depression in the ground-water surface, and hydrologically confine all of the leachate. Depending on the capacity of the treatment facilities, a cover to reduce infiltration may or may not be necessary.

The amount of water that would have to be treated if complete collection of leachate is planned can be roughly estimated by adding the amount of infiltration expected through the cover to that expected through the sides of the site. For example, assume that a landfill with dimensions of 300 feet by 300 feet by 20 feet and a cover that allows 5 inches of infiltration per year is placed in materials with a permeability of 10^{-2} gallons per day per square foot, or slightly less than 10^{-6} cm/sec. Also assume that the level of the outlet drain has been adjusted so that the hydraulic gradient across the sides and base of the site is less than 1 ft/ft, and that the top of the zone of saturation intersects the sides of the site 10 feet above its base. Under these conditions, the amount of water infiltrating through the surface would amount to approximately 3×10^5 gallons per year:

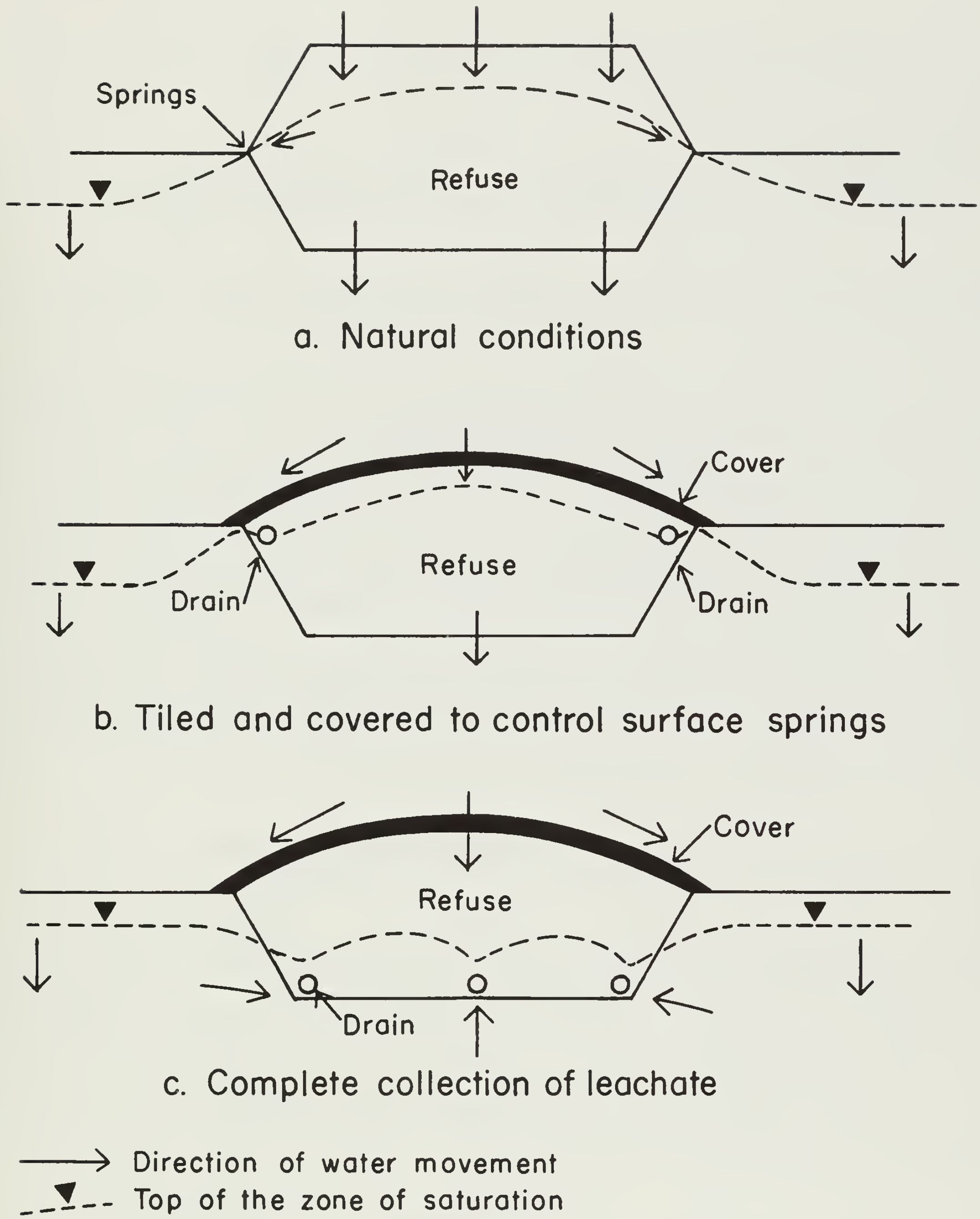

Fig. 2 - Hydrogeology of a landfill with schemes to control spread of leachate. Landfill intersects zone of saturation. Earth materials have low permeability. Site is in a ground-water recharge area.

$$300 \text{ ft} \times 300 \text{ ft (surface area)} \times 5/12 \text{ ft (infiltration)} \times 7.48 \text{ (gal/cu ft) gallons} = 2.81 \times 10^5 \text{ gal/yr.}$$

The amount of water moving into the landfill through the sides and base would be approximately 4×10^5 gallons per year:

$$4 \times 300 \text{ ft} \times 10 \text{ ft (area of sides below water table)} + 300 \text{ ft} \times 300 \text{ ft (area of base)} \times 10^{-2} \text{ gpd/ft}^2 \text{ (permeability)} \times 365 \text{ days} \times 1 \text{ ft/ft (hydraulic gradient)} = 3.72 \times 10^5 \text{ gal/yr.}$$

The amount of water that would have to be handled would, therefore, be approximately 700,000 gallons per year, or an average of 1,900 gallons per day.

Most of the surface infiltration would occur during the spring or fall when the soil moisture is high, rather than in the growing season when the soil moisture has been reduced by transpiration, so we might assume a maximum of 100,000 gallons from this source during a 30-day period. This amount, plus 1/12 of 4×10^5 gallons—approximately 30,000 gallons—which enters the pit from the sides and bottom, would amount to a maximum monthly flow of 130,000 gallons, or an average daily flow at this time of 4,300 gallons (about 3 gallons per minute). Storms would probably cause higher flows for short periods; however, the landfill itself has some storage capacity, and, if necessary, additional storage could be constructed, possibly in conjunction with the treatment facilities. Although this calculation assumes that the hydraulic gradient into the landfill is 1 ft/ft, in actual practice it may be possible to adjust the level of the outflow for a much smaller gradient, making the total ground-water contribution correspondingly less than that calculated.

Environment 2—Highly Permeable Materials, Recharge Zone, Below Water Table

Figure 3 illustrates a landfill in an environment where the earth materials have high permeability, the site is in a recharge area, and the refuse is deposited below the top of the zone of saturation. Such an environment may be present in outwash plains and in upland morainal areas in northeastern Illinois. Existing excavations are commonly gravel pits. Under natural conditions (fig. 3a), springs will probably not be present. Leachate will be produced by infiltrating precipitation and by ground water moving through the refuse, providing that a ground-water mound has not formed and there is some horizontal gradient.

Partial control of the production of leachate could be achieved by installing a cover designed for maximum runoff. This would reduce infiltration, but leachate might still be produced by ground water from the sides of the fill moving through the refuse. The amount of ground water moving through the refuse could be reduced or eliminated by installing a liner (fig. 3b). At a given rate of infiltration, minimum leachate production will be attained when the permeability of the liner is just low enough to allow a ground-water mound to develop. The amount of leachate produced would then depend on the amount of infiltration through the cover.

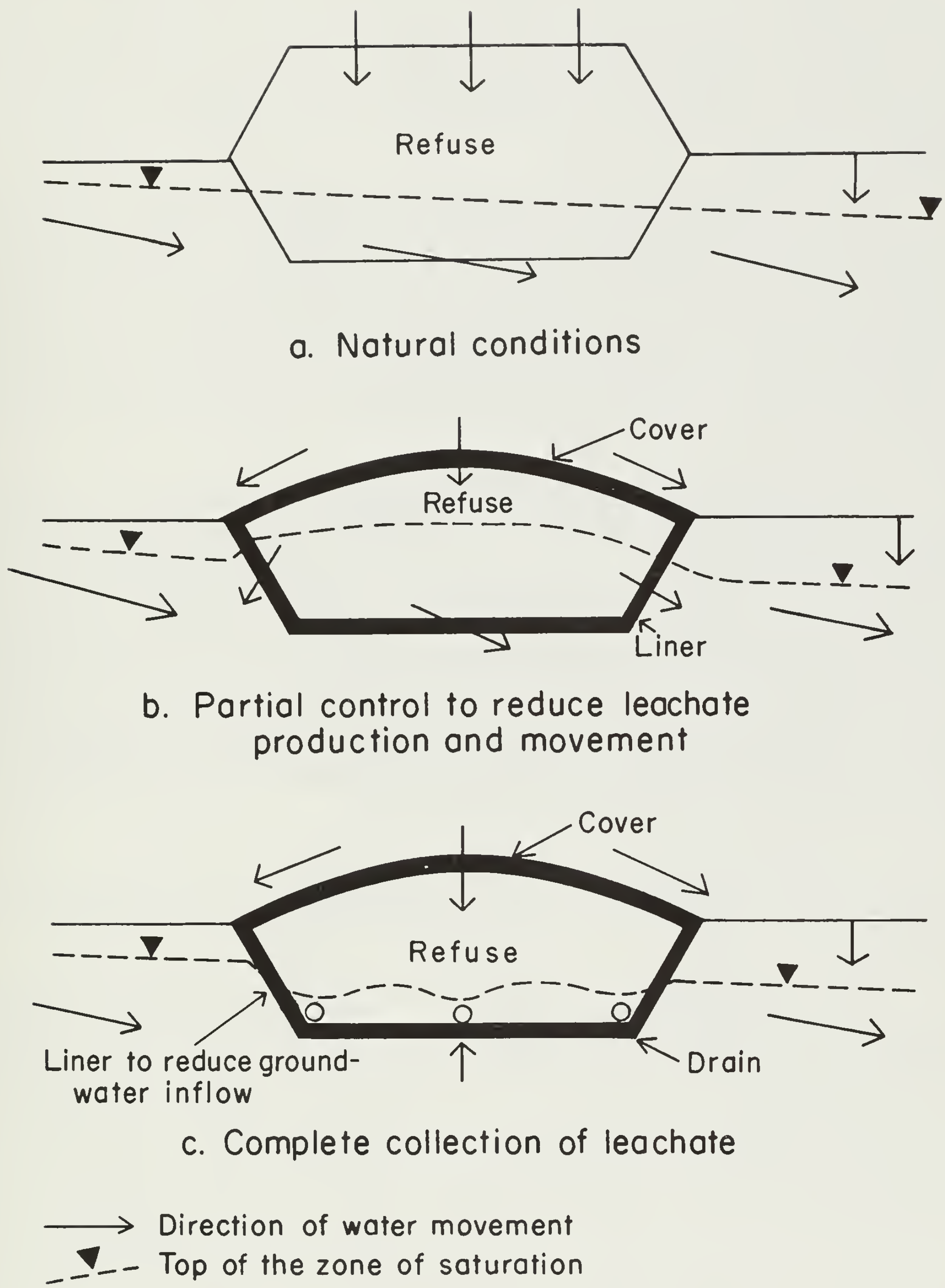

Fig. 3 - Hydrogeology of a landfill with schemes to control spread of leachate. Landfill intersects zone of saturation. Earth materials have high permeability. Site is in a ground-water recharge area.

In humid climates a lined site without a cover would be likely to fill with leachate that would, if the liner reached the ground surface, move out on the surface as springs along the margin of the landfill. If the liner did not reach the surface, the leachate would move into the surrounding materials. Therefore, unless leachate collection facilities are planned, the permeability of the liner must be compatible with the amount of infiltration anticipated.

For complete control, a drainage system at the base of the landfill can be used to collect all of the leachate (fig. 3c). This leachate must then be pumped or gravity-drained to a treatment facility. The amount of leachate to be handled can be partially controlled by adjusting the level of the outlet, by installing a liner below the top of the zone of saturation to inhibit groundwater movement into the site, or by using a cover designed for maximum runoff. The concentration and quality of leachate also are likely to be affected by these measures because they would influence the rate at which the refuse is leached.

The combination of materials of high permeability, a recharge zone, and refuse placed within the zone of saturation seldom offers a naturally protective landfill environment, but in many cases a landfill could be satisfactorily constructed. A major disadvantage to placing landfills in such an environment is that control facilities on the completed site must be supervised until the landfill has stabilized to the extent that all of the leachate produced is released into the surrounding materials. The time required for such stabilization to take place is difficult to estimate, but may be many tens of years. Measures to speed decomposition would probably be taken. Designs similar to that depicted in figure 3c are particularly suited for accelerating decomposition by collecting and recirculating leachate.

Environment 3—Highly Permeable Materials, Near Discharge Zone, Below Water Table

Figure 4 illustrates a landfill in highly permeable materials near a discharge zone. The refuse is placed below the top of the zone of saturation. In northeastern Illinois, this kind of environment may be found in valley flats adjacent to streams and in kettles in morainal topography. The excavations on the site would include gravel pits and borrow pits. Under natural conditions (fig. 4a), the refuse in this type of environment would be leached by infiltrating precipitation, and probably by ground water as well. There is little likelihood that the leachate will percolate downward to deep aquifers or move laterally, except toward the stream (unless it reaches the pumping cone of a near-by well). As shown in figure 4a, dissolved solids from landfills in this environment may move to near-by bodies of surface water. Commonly, however, sufficient attenuation of the dissolved solids may have taken place in the subsurface so that after dilution in the surface water the discharge will not produce noticeable effects.

Discharge could be partly controlled (fig. 4b) by the installation of a cover and liner, as was true for environments 1 and 2, and these facilities could be used to reduce to very low levels the amount of dissolved solids leaving the site.

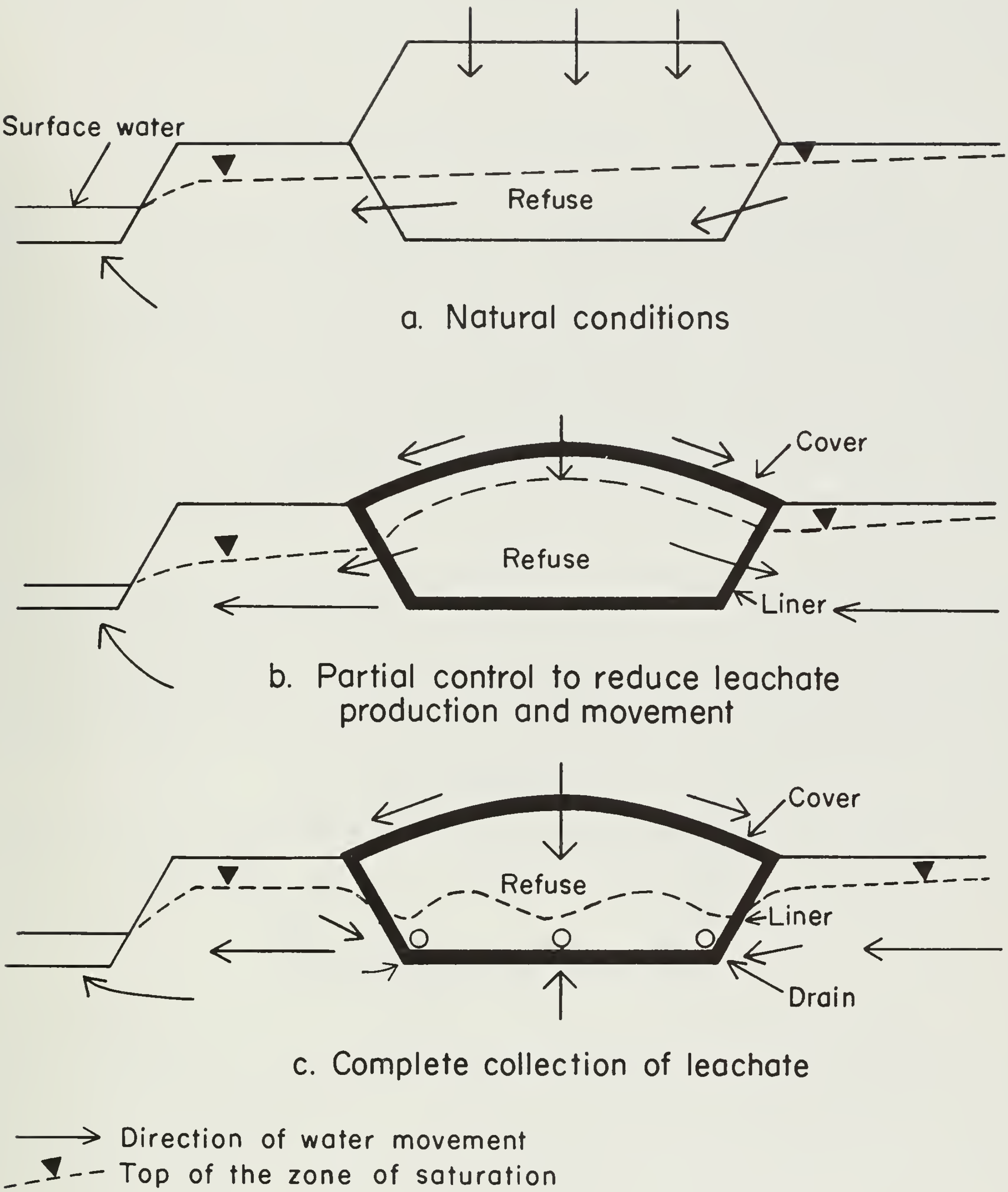

Fig. 4 - Hydrogeology of a landfill with schemes to control spread of leachate. Landfill intersects zone of saturation. Earth materials have high permeability. Site is near a ground-water discharge area.

Complete control of all discharge from this type of landfill could be achieved with a cover, a liner, and collection facilities (fig. 4c). An alternate means of control would be installation of shallow collection facilities outside of the landfill, between the landfill and the stream.

Environment 4—Highly Permeable Materials, Recharge Zone, Above Water Table

Figure 5 illustrates a landfill in an environment where the materials are of high permeability, the area is a ground-water recharge zone, and the refuse is deposited above the top of the zone of saturation. This type of environment is found in northeastern Illinois gravel deposits in morainal uplands. Existing excavations are usually gravel pits. Under natural conditions (fig. 5a), no springs will be present. The leachate will be produced by infiltrating precipitation and will move downward into the underlying materials. There is some question as to the amount of attenuation this leachate will undergo as it moves downward through the permeable materials to the top of the zone of saturation. However, the data at present available suggest that attenuation of the dissolved solids in the leachate as it travels this interval is not sufficient to insure safe disposal.

Partial control could be achieved by installing a cover designed for maximum runoff (fig. 5b). If this is still not adequate, maximum control could be achieved by installing a liner at the base of the landfill and a collection system in addition to the cover (fig. 5c). A collection system above the zone of saturation is less efficient than one within the zone of saturation because its effectiveness depends in part on the permeability of the liner. Theoretically, complete collection is impossible unless the liner is impermeable, but it may be possible to reduce leakage to very low levels.

Lateral migration of landfill gases is most likely in this environment and may create major problems, unless the fill is well vented.

INVESTIGATION OF LANDFILL SITES

The hydrogeology of a proposed landfill site must be understood if the landfill is to fit that particular environment. The investigation for a sanitary landfill might proceed in two steps: first, a preliminary exploration of the site (Cartwright and Sherman, 1969) should be conducted so that its feasibility for a landfill can be determined and a tentative design can be formulated; second, a detailed survey should be made so that a report on general design (required in Illinois by the Environmental Protection Agency) can be prepared.

The three hydrogeologic factors that must be investigated—the type of earth materials present, the ground-water flow system, and the position in relation to the top of the zone of saturation—have already been discussed. The drainage conditions and the likelihood of flooding must also be considered in designing a landfill.

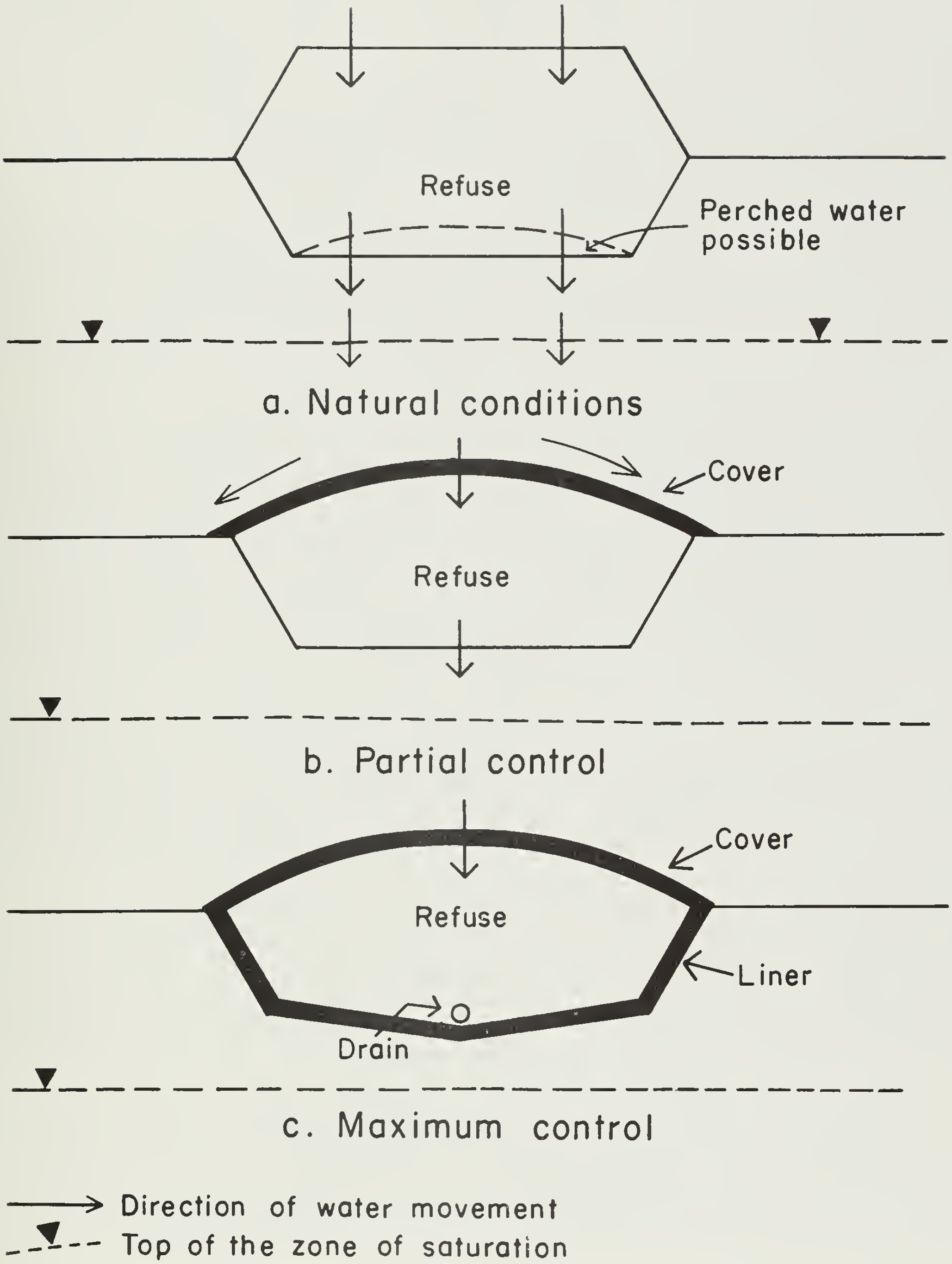

Fig. 5 - Hydrogeology of a landfill with schemes to control spread of leachate. Landfill does not intersect zone of saturation. Earth materials have high permeability. Site is in a groundwater recharge area.

Preliminary Exploration

The objects of the preliminary investigation are to determine the feasibility of the site for a landfill and to find an appropriate design. The steps outlined will generally be adequate to give a general idea of the materials present and involve relatively little expense. In some cases, however, they will be inadequate and it may be necessary to make soil borings and water-level determinations. The borings, if properly planned, may also be useful in subsequent phases of the investigation.

In many cases, a preliminary determination of what materials are most likely to be present at the site can be made from data on file at the Illinois State Geological Survey; these can be verified by the examination of excavations such as borrow pits and gravel pits in the area. Other information may be available from well drillers or the local Soil Conservation Service Office.

A preliminary estimate of the position of the site within the ground-water flow system can often be made from an examination of the topographic maps of the area and a brief reconnaissance. If the site is in an upland, it is probably in a ground-water recharge zone, and if it lies in a lowland area it is most likely in or near a ground-water discharge zone. Ground-water use in the immediate vicinity must be investigated, and the number and size of near-by wells should be checked to determine whether the site is likely to be in a cone of depression caused by heavy pumping. In Illinois, the State Water Survey may be asked for assistance in this regard.

The top of the zone of saturation in the area will be reflected by water levels in near-by swamps, excavations, lakes, and streams; vegetation such as cattails and marsh grass indicate a water level near the ground surface. If the material in the vicinity of the site is clay, the top of the zone of saturation is probably within 10 feet of the ground surface, but the exact level is somewhat difficult to determine.

In moderately permeable materials, the elevation of the water in shallow dug or driven wells will generally reflect the top of the zone of saturation. The elevation of the water in wells deriving their water from deeper aquifers probably reflects the ground-water potential in those aquifers and in most cases should not be used to estimate the depth of the top of the zone of saturation.

A description of the preliminary findings and a tentative design for the landfill should be reviewed informally with the Environmental Protection Agency, Bureau of Land Pollution Control, Springfield. If the preliminary results are favorable, it will be necessary to substantiate the preliminary findings and to propose a detailed final design in a report.

Exploration for Design of the Landfill

The amount and type of additional data to be gathered will depend on the hydrogeology and the design of the particular landfill. For example, if a landfill is to be located in an abandoned quarry and the intended design calls for complete collection and treatment of the leachate, less detailed information on the geology and hydrology may be required than if the landfill is designed so that dissolved solids will be allowed to migrate some distance from

the site. In the first instance, the hydrogeologic data critical to the design will probably be readily available. In the second, a more extensive exploratory program will generally be necessary. Some of the techniques that can be used in gathering this additional data are briefly described in the following section.

Further investigation of the earth materials in the vicinity of the site will generally require borings and collection of representative samples such as those obtained with a split-spoon sampler. Commonly, undisturbed samples, such as are obtained from cores, will be needed for the purpose of determining permeabilities. If the borings are to be used later for water-level determinations and they have been drilled with fluid containing a mud additive, they must be washed clean. Water-level determinations will commonly be necessary for the design report.

Shallow well points are generally adequate for determining the top of the zone of saturation. These usually should be set 5 to 10 feet below the top of the zone of saturation so that they will not go dry during seasonal fluctuations. The annulus of the well point should be backfilled with material of low permeability above the zone of saturation and with permeable materials below the top of the zone of saturation. In fine-textured materials, considerable time is required for water levels in the standpipe to reach equilibrium with natural water levels. To shorten this time, a standpipe of small diameter (¼- to ½-inch) is usually used. Water levels may also be stabilized manually by adding and subtracting small amounts of water to the standpipe until a reversal in water level is obtained.

In order to define the ground-water flow system, both the horizontal and the vertical component of ground-water flow must be measured. The well points used to determine the elevation of the water table are suitable for determining the horizontal component of flow. A piezometer is necessary for determining the vertical component of ground-water flow. A piezometer is an instrument for measuring the water pressure at a specific depth within the zone of saturation. For landfill investigations it may consist of a well point attached to a standpipe with a seal such as bentonite in the annulus between the standpipe and the wall of the boring just above the screen. This unit will show the water level (head) of the interval between the base of the seal and the bottom of the boring. The vertical component of ground-water flow is determined by measuring the relative water levels in a shallow well point and a deeper piezometer, both of which are commonly installed in the same boring.

As the same problems are involved in stabilizing a piezometer in fine-textured materials as are involved in stabilizing a well point, the screened portion of the piezometer should be set in the most permeable unit available.

Water Balance

In most cases a water balance, that is, an estimate of the amount of water that will move into and out of the landfill and by what paths, will be a critical part of the design report. Where collection and treatment facilities are to be used, a water balance is necessary for proper design. In any case, it is an excellent method of clearly defining the effect the landfill is likely to have on the surrounding ground and surface waters.

If the hydrogeology involved in this water balance is relatively simple, it may be possible to arrive at a reasonably accurate estimate of inflow and outflow based on determinations of permeability and hydraulic gradient. In many cases, however, the hydrogeology is complex, and determinations of these quantities, particularly permeability, at different locations may vary widely. In such cases an approximate water balance based on estimates of permeability and gradient that are on the conservative side—that is, are maximum reasonable values from a sampling of the data—is probably the most feasible approach. Some guide lines for compiling a water balance were given in the discussion of landfill design, and the subject also was discussed by Hughes, Landon, and Farvolden (1971).

Monitoring

Where monitoring points are required, their position will depend on the hydrogeology and water use in the area. Monitoring points designed to detect dissolved solids moving downward through the base of the landfill should be constructed in a manner similar to that discussed previously for piezometers, with a seal in the annulus from land surface to the top of the screen. If this seal is not properly constructed, contaminated water may move down the annulus and show pollution beneath the landfill where none exists.

Wells drilled to sample shallow, lateral ground-water flow should be located outside the landfill and extend some distance below its base. These sampling points should be constructed in the same manner as the shallow well points previously discussed. In general, the most critical water-monitoring points are down hydraulic gradient from the landfill.

Water samples should be taken in advance of the filling operation and should include water from near-by wells and surface water. To make sure the samples are representative, sampling points should be pumped and bailed after they have been installed and shortly before the samples are taken to remove any water that may have entered during their construction.

It is suggested that the initial water samples undergo a rather complete analysis, including tests for chloride, sulfate, biological oxygen demand, chemical oxygen demand, alkalinity, sodium, and conductivity. Further sampling could be at quarterly intervals and might include analysis of conductivity and chlorides only. The precise procedure and interval will generally be prescribed by regulation. If periodic sampling indicates that the water quality in these points is changing, additional sampling points and more frequent sampling may be necessary.

If the leachate is to be pumped or gravity-drained from the landfill, monitoring points will be necessary to regulate the level of the outflow so that a gradient into the site can be maintained. These will be permanent installations and should be constructed accordingly.

CONCLUSIONS

Almost all waste-disposal operations contribute some microbial and/or chemical contaminants to the environment. At some sites the natural environment

contains or attenuates these contaminants satisfactorily, and at other sites man-made controls must be added.

Landfills could be constructed in almost any of the hydrogeologic environments present in northeastern Illinois, provided that a suitable design is used for each particular environment and that the use of the site after the fill has been completed is considered. Where natural conditions are inadequate to reduce to a tolerable level the dissolved solids content of leachate moving from a landfill, engineering techniques may be employed to achieve this purpose. The less suitable the environment, the more complex and expensive these techniques must be. In some cases it may be economical to so improve an otherwise unsuitable site if money can be saved on such items as land costs and transport of refuse.

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